22. METEORS AND INTERPLANETARY DUST
(MÉTÉORES ET LA POUSSIÈRE INTERPLANÉTAIRE)

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1. Introduction

This report follows its predecessor in attempting to review significant developments in the field rather than constituting an extensive bibliography. As before, several sections have each been contributed by one author and the President has combined these editorially and attempted to ensure that all major areas have been adequately covered. Thanks are due to individual scientists who responded to requests for information from the authors of sections, to the authors of each section for the care with which they prepared the material, and to Dr. A.N. Simonenko for her help in preparing a summary of recent work in the U.S.S.R. which was of great value in editing the individual sections. As before, references from Astronomy and Astrophysics Abstracts have been used when available. Attention is drawn to the published proceedings of two major symposia and a volume of significant review papers:

IAU Colloquium 39, "Comets, Asteroids, Meteorites - Interrelations, Evolution and Origins", ed. A.H. Delsemme, University of Toledo, 1977. (20.012.049)

Cratering Symposium, "Impact and Explosion Cratering, Planetary and Terrestrial Implications", ed. D.J. Roddy, R.O. Pepin and R.B. Merrill, Pergamon Press, New York, 1978.

"Cosmic Dust", ed. J.A.M. McDonnell, John Wiley & Sons, New York, 1978.

References to these volumes are abbreviated in the text to Coll. 39, Crat. Symp. or Cosmic Dust.

There is a certain amount of unavoidable overlap in the nine sections which follow, for example, an effect involving meteors and the Earth's atmosphere (section 8) may be the subject of an observational radar program (section 3) or a theoretical interpretation (section 5). In combining the sections to form this report, some of this overlap has been removed and the reader is referred to another section, but some has been allowed to remain since the emphasis is likely to be on different aspects of the work in different sections. The use of a single reference list at the end avoids repetition of those references not found in Astronomy and Astrophysics Abstracts. As editor of the report the President accepts responsibility for its shortcomings in the form of errors and omissions.

It is with sorrow that we record the loss of a noted meteor astronomer and former President of the Commission, V.V. Fedynskij, and also the death of a consultant to the Commission, J.W. Rhee.

2. Photographic Meteors
(Z. Ceplecha)

The photographic recording of the Innisfree meteorite in flight by two stations of the Canadian MORP camera network on 1977 February 6, $2^h 17^m 38^s$ UT was a significant achievement since the previous IAU Report. The main piece was recovered by Halliday 12 days after the fall, during the first day of systematic search by snowmobile. This is the third meteorite with double-station scientific photographs, Příbram being the first and Lost City the second. Innisfree is an L-type chondrite

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and had a low-inclination orbit intermediate between Příbram and Lost City in its eccentricity (Halliday et al. 1978). Nine fragments with a total mass of 4.6 kg have been recovered, six of them exceeding 300 g. At least five separate trails can be studied and the fragments fade out with velocities between 2.7 and 4.7 km s^{-1}. Identification of at least some of the trails with known recovered masses permits a study of the luminous efficiency between 20 and 30 km height for velocities below 10 km s^{-1}.

The Innisfree fireball was photographed during routine operation of the Canadian MORP network which records about 50 bright meteors per year by 2 or more of the 12 stations. More than 300 such meteors have been photographed by the end of 1978. The area of atmosphere photographed under good observing conditions by at least two stations is recorded routinely and recent coverage has averaged 8×10^8 km^2h per year. Unsuccessful meteorite searches were conducted in Saskatchewan during December 1975-January 1976 and in Manitoba during May 1977.

The European Fireball Network (EN) continued in routine operation with major portions directed by Ceplecha at Ondřejov Observatory of ČSAV; by Porubčan at the Astronomical Institute of SAV, Bratislava; and by Kirsten at Max-Planck-Institut für Kernphysik, Heidelberg. Austria has joined the project with two of 11 stations already in operation, using all-sky mirror cameras, under the direction of Polnitzky (Universitäts-Sternwarte, Wien). Two stations in the Netherlands (Meteor Section, Leiden; Betlem) provide a partial connection of the Continental network with the British portion, which now operates 60 stations under the direction of Hindley (BAA Meteor Section). In total, the European Network now consists of more than 100 stations with typically smaller spacings among stations than the other networks. Five of the Czech stations are now equipped with new cameras using fish-eye lenses (f = 30 mm, 1:3.5, field of view 180°) which photograph meteors down to zero magnitude. Data on current fireballs are published regularly in SEAN Bulletin (Smithsonian Institution, Washington). Ceplecha (20.104.025) has published details of 42 fireballs brighter than magnitude -8 photographed in Central Europe from 1947 to 1976.

Data on 322 fireballs photographed by the Prairie Network in the U.S.A. from 1963 to 1975 have been published by McCrosky et al. (1976, 1977). This is the most extensive body of data available on fireballs and our knowledge of their orbits and the application of theory to the phenomenon of the atmospheric entry of large bodies relies greatly on this material.

Recently a new network for fireball photography was established in the U.S.S.R. under the Committee on Meteorites of the Academy of Sciences and the Odessa Astronomical Observatory. A camera system with six objectives records most of the sky at each of 25 stations in the southwestern part of the U.S.S.R. (17.104.059; 18.104.046) with typical separations of about 200 km between stations. Special attention has been devoted to the problem of determining the time of appearance of fireballs and tests of the network have been described by Kramer et al. (20.032.046). The method of instantaneous exposures gives evidence of providing valuable insight into the nature of fragmentation in fireball-producing meteoroids.

Several stations in central Japan now operate automatic fireball cameras (report from H. Tanabe, Tokyo). Serious planning is in progress to establish a fireball camera network in India under the direction of the Physical Research Laboratory in Navrangpura.

Although fireballs have recently been the main objective of meteor photography, the classical small-camera work has continued. In New Mexico highly automatic cameras have been used by Harvey and Tedesco to give geometrical and dynamical data for meteor spectra photographed at the same stations (18.104.051, 19.104.028).

The small-camera program at Ondřejov Observatory ended in 1977 after 26 years of systematic operation and the reduction of the meteor data is well advanced. The support data for meteor spectra are now provided by the fish-eye lenses used in the EN project.

Photographic programs have been continued by the American Meteor Society in Jacksonville, Florida (Simmons) during significant meteor showers and by the Meteor Section of the Netherlands Association for Astronomy and Meteorology in Leiden (Betlem). At the Kiev Astronomical Observatory, Benyukh (18.104.021) has made a special study of meteor flares using photometry of double-station photographs. The volume of the luminous gas in flares, radiated energy, density of radiating atoms, masses and densities of meteoroids were studied. Also at Kiev, periodic changes of relative mass loss during atmospheric ablation were found and the periods correlated with the position of maximum light (18.104.022).

Fifty orbits of meteors photographed by the Odessa Observatory between 1965 and 1972 were reduced and published by Kramer and Markina (18.104.002).

The great importance of radiative heat transfer for the ablation of large meteoroids in continuum flow was recognized by Petrov and Stulov (1975), by ReVelle (1976) and by Padevět (19.104.014). ReVelle's physical theory was found to be consistent with photographic observations of fireballs. ReVelle and Rajan (1978) applied the new luminosity equation to the three photographed chondritic meteorite falls and derived "photometric" masses 5 to 10 times less than previous estimates, in good agreement with "dynamical" masses as well as laboratory experiments (05.104.007) and cosmic ray track studies (Rajan). The ablation coefficient near peak ablation was found to be 0.02 to 0.03 s^2 km^{-2} and preatmospheric masses were estimated as $\sim$60 kg for Lost City, $\sim$20 kg for Innisfree and 250 to 3000 kg for Příbram. Thus the long standing paradox of dynamic versus photometric masses appears to be solved.

The previous classification of photographic fireballs by Ceplecha and McCrosky (18.104.048) was extended by Ceplecha (Coll. 39) to include fainter meteors, covering a total mass range from 10^{-4} g to hundreds of tons. Five groups of bodies were found and proposals were made relating each to other bodies in the solar system. ReVelle and Wetherill (1978a) applied the new physical theory of fireballs to study the end heights of PN fireballs. Using Lost City and Innisfree data for calibration they found 30% within ±1 km and another 20% within ±3 km of the theoretical end height values for ordinary chondrites. The remainder have end heights up to 10 km too high for their dynamic masses. Since only fireballs with good dynamical data were used there may be a selection effect masking the real abundance of objects with low mechanical strength and large end heights. The classifications by ReVelle and Wetherill, based on dynamic mass vs end height, are similar but by no means identical to those of Ceplecha and McCrosky, based on photometric mass vs end heights.

Rajan et al. (1978) used ReVelle's theory with preatmospheric masses deduced from cosmic ray track studies to derive initial velocities for several meteorites. If visual radiants are available then orbits can be computed which are not much worse than from fireball photographs.

Padevět (19.104.014 and 1978) proposed a theory of fireballs in which an effective dynamic cross-section of a meteoroid in continuum flow depends strongly on the coma around the meteoroid. The theory predicts even larger initial masses than the classical photometric values, in contrast to ReVelle's theory. Only qualitative comparisons with fireball observations exist at present but the theory should not be discarded until more quantitative tests are available.

Carusi and Massaro (17.105.090) criticized the data published by Rawcliffe et al. (11.104.009) for the daylight fireball of 1972, August 10. The original velocity data are inconsistent and should be corrected. Also, there is a misleading comparison between the argument and longitude of perihelion in the orbital data by Carusi and Massaro.

Using airwave data from a nuclear test monitoring system (∿1 to 10 dynes cm^{-2} and ∿0.3 to 0.01 Hz) ReVelle and Wetherill (1978b) computed global influx rates for meteoroids between 10^6 and 10^{10} g. They found an annual energy flow of 2×10^{21} ergs and an estimated annual flux of 10^9 g. These data represent a first step into the intermediate mass range of interplanetary bodies where observations are lacking and only interpolations have been possible (Kresák 1978a).

3. Radar Meteors
(W.G. Elford)

The extensive radio meteor data obtained by the Harvard-Smithsonian group during the synoptic year, 1969, have been searched for stream associations and 275 streams have been found amongst the 19,698 orbits (17.104.003). A number of cometary associations have been confirmed but no discrete levels of meteor heights occur in the data. Low inclination streams were often detected at both nodes. The statistics of the synoptic year meteor data are available on magnetic tape (20.104.050).

McIntosh and Simek (19.104.025) have determined the heights of 18,000 radar meteors from the rate of decay of the echoes at a frequency of 33 MHz. The mean height is almost independent of the trail line density and the small variation with elevation of the apex (2 km for 60°) is entirely explainable in terms of the variation of the mean velocity with elevation of the apex. When corrected for the apex variation the mean height is almost constant throughout the year at 93 km, while the width of the distribution varies from 5 km in summer to 9 km in winter. The height distribution, decay times and durations of meteors have also been measured at a frequency of 2 MHz in Australia (17.104.004). In this case the mean height of underdense echoes was 104 km and the width of the distribution was 12 km.

The increase in the rate of occurrence of echoes from overdense trails after sunrise has been thoroughly studied for a large body of data obtained with the Ottawa patrol radar during the period 1963-67 (20.104.017). A rapid increase in the rate by a factor of two just after sunrise is followed by a slow decrease during the day. The phenomenon is attributed to changes in the ionization loss processes involving O, O_2 and O_3 mentioned in the previous report. It is pointed out that the consequences of these rate changes for the estimation of meteor fluxes, sporadic radiant sources and mass distributions could be significant and should be examined. Baggaley (17.104.034) has drawn attention to the possibility of rapid initial deionization due to collisional electron-ion recombination in trails brighter than zero magnitude, but points out that the volume ionization density may be too low for such processes to be important. Further data on initial trail diameters at low heights are required.

The discrepancy between the theoretical and observed variation of ambipolar diffusion coefficient with height has been re-examined (14.104.060) and it is considered that, below 85 km, ionization is removed by the oxidation-dissociation process mentioned earlier, while above 95 km, distortion of the ionized column by irregular winds produces secondary reflection points.

Further studies have been carried out on head echoes (20.104.027, 20.104.028) and on the lack of aspect sensitivity of some overdense trails (17.104.008). No correlation has been found between the occurrence of head echoes and any geophysical indices.

The theory of radiowave backscattering from a meteor trail has been re-examined using a full-wave treatment (20.082.025) and reflection coefficients calculated.

Some inconsistencies have been found in previous theoretical studies; the results of the new work are in accord with earlier experimental observations of polarization ratios.

The relation between temperate-zone sporadic E and meteor rates has been placed on an orderly basis by the identification of three classes of E_s produced by meteors (18.083.083, 18.083.084). One of these classes shows positive correlation with radar meteor rates. At high latitudes forward scatter radar meteor rates have been shown to be correlated with the occurrence of sporadic E with a delay of about 3 hours in summer and 7 hours in winter (18.083.018).

The Quadrantid meteor stream has been studied at both Sheffield (20.104.014) and Ottawa (20.104.056). The time of occurrence of stream maximum is found to vary with meteor magnitude and large variations in meteor fluxes have been observed from year to year. The importance of simultaneous observations from several stations well distributed in longitude has been stressed.

Bibarsov and Chebotarev (18.104.018) studied some properties of meteoroids and their ionized trails. The results of four-station radar observations indicate that echoes from the trails of 10^{-3} to 10^{-2} g particles are two or more times shorter than theoretical values. Several authors (18.104.011, 18.014.012) describe a model for the influx of meteoric matter based on radar observations. Several papers published in the U.S.S.R. (18.104.010, 18.104.004, 18.104.025) deal with physical characteristics of meteors and their trails including fragmentation, resonance scattering, diffusion and convection. The problems are complex and our knowledge is still quite incomplete. Kolmakov and Fialko (20.104.008) examined the influence of the earth's magnetic field on the motion of ionized meteor trails. This phenomenon can be important only for very bright meteors.

4. Meteor Spectroscopy
(P.M. Millman)

In recent years there has been a tendency for systematic programs of meteor spectroscopy to convert to a series of combined observations during specified periods, for example, favourable nights near the maxima of meteor showers. This is a natural result of large data aquisition, and a general shortage of manpower for reductions. The program operated by the Ondřejov Observatory in Czechoslovakia is still active on a routine basis, and this may also be true, to a certain extent, of similar activity in the U.S.S.R. and Japan. However, the NASA Langley photographic meteor program, directed by G.A. Harvey, ceased operation in 1976; and the Dudley-Smithsonian-National Research Council cooperative program was terminated at the end of 1977, after recording vidicon data on some nine major meteor showers in a four-year period. Two outstanding fireballs, with a luminosity comparable to that of the moon, were photographed with multiple grating-spectrographs; one, near Ottawa, Canada, on November 6, 1975; the other, near Kamyk, Czechoslovakia, on March 2, 1976. To acquire statistical data on the spectra of faint meteors there has been an increased emphasis on the use of electronic, image-intensified recording systems, operating with video-tape for information storage.

Russell has continued his long-term observation of Perseid meteors with a very successful campaign in 1978, when he secured 19 spectra in 4.6 hours with one spectrograph (Sky and Telescope 56, p. 465, 1978). This shower should be watched as we approach the predicted return of Comet Swift-Tuttle near the year 1981. Russell has also presented possible oxygen 5577 A green-line correlation (14.104.090) in Perseid spectra. Nagasawa (1978) has carried out detailed analyses of two Leonid spectra photographed in 1965. He finds a high abundance of Mg, Fe, and Co, with a low abundance of Na, Ca, and Mn. Stauffer and Spinrad (1978) have measured the intensity of 65 lines identified in a sporadic meteor spectrum recorded with the 120-inch Lick telescope. Harvey has analysed the spectra of two high-velocity meteors (20.104.013 and 1978). He has also studied the air radiation for N, O, and N_2 in meteor spectra, and made a tentative identification of OH in the near ultra-violet (19.104.005, 20.104.012). Using four different filters Hajduková has compared the observed colour indices of 3 meteors with the corresponding spectra (18.104.040).

At Ashkhabad in the Turkman SSR a team of astronomers has continued a program of meteor spectroscopy, using high-sensitivity television equipment. Observations on this program were commenced in 1972 (18.104.017) and more recently techniques for the photometric reduction of the spectra recorded have been developed (18.104.019, 19.104.021). Of particular note is a determination of the decay constant for the 5577 A line of O I, and the identification of the 4278 A band of N_2^+, with a decay constant similar to that for the oxygen line (Mukhamednazarov and Smirnov 1977, Mukhamednazarov 1977). Airborne vidicon observations were combined with ground radar records of the 1976 Quadrantid meteors on the Dudley-Smithsonian-NRC cooperative program (17.104.010). Millman and Clifton (1979) have developed techniques for the photometric analysis of meteor spectra, using a direct computer readout from a digitized video-tape.

The theoretical work dealing with meteor spectra has concentrated on explaining the various forms of enduring luminosity remaining along the trajectory after the passage of the meteor head. A short paper from Ashkhabad (19.104.007) deals with possible reactions producing the 5577 A line of O I. Rajchl (13.104.029, 14.104.008) has proposed mechanisms involving NO_2 and NO to explain meteor trains. Baggaley in New Zealand has been the most prolific worker in this subject. After surveying all possible relevant reactions in the upper atmosphere (12.104.027) he concludes that both NO_2 and NO are quite inadequate for the production of train luminosity (14.104.007, 14.104.059). The possible contributions of Na and K (14.104.013, 18.104.006, 19.104.022) and of metallic atoms and oxides (17.104.001, 19.104.015) have been discussed. A red afterglow in meteor trains might be the O_2 red atmospheric bands (20.104.026). After a detailed study of possible reactions producing the 5577 A line of O I (17.104.040, 18.104.014, 20.104.016, 20.104.034, Baggaley 1978). Baggaley concludes that a two-step process involving dissociative recombination of O_2^+ produced by meteoric O^+ ions is the most likely. Poole (1978) emphasizes the importance of the oxidation of meteoric metal ions by ozone, followed by dissociative recombination with electrons, to explain the enduring trains of meteors in the magnitude range 0 to -5.

As a guide to meteor spectroscopy from space vehicles, Meisel (1976) has produced a very useful summary of features to be expected in the near-ultraviolet. The evidence for the chemical composition of cometary meteoroids provided by meteor spectra has been compared with data from other areas of research in two general reviews (20.104.052, Millman 1979).

5. Physical Theory of Meteors
(D.W. Hughes)

The ablation of the incoming meteoroid and the physical diffusion and chemical recombination taking place in the meteor that it forms have been studied in detail. Hawkes and Jones (14.104.026) assumed that meteoric bodies were composed of 10^{-6} g grains held together by a lower boiling-point "glue", these being detached when the glue boils. For meteors fainter than $+5^m$ this occurs above the radiation ceiling and the heights of these meteors are mass independent. Jones and Hawkes (13.104.010) showed that the vertical train length is about 6.7±0.7 km for meteors fainter than $+8^m$ and that the solid, compact meteoroid model must be abandoned. Jones (1978a) goes so far as to interpret his meteor data in terms of the spin period of the incident meteoroid. The initial radius of meteor trains and its effect on the train's radar reflectivity as a function of wavelength have been investigated by Delov and Zhukov (14.104.023), Delov (1975) and Delov (1978a). Poulter and Baggaley (1978) reinterpret radio-meteor observations in terms of a modified radio wave scattering theory. Delov (1978b) considered meteors of magnitudes between 7 and 8 and studied the variation of the length of the ionization curve and vapourization altitude as a function of the geocentric velocity of the incident meteoroid. Bibarsov and Chebotarev (18.104.018) are also in favour of short trails.

The theory of the ablation of large meteoroids associated with fireballs and meteorites has been studied in detail and significant modifications to the previous theories have been proposed, supported by observational data (ReVelle 1976, ReVelle and McIntosh 1978, see also section 2 of this report).

Jones (14.104.060) reinvestigated the variation of the ambipolar diffusion coefficient with height (see section 3 above). Novotný (1978) and Andreeva et al. (19.104.044) also looked into this problem.

The ionic chemistry of meteor train formation and development has been thoroughly investigated by Baggaley and Poole. The effect on the luminosity is discussed by Poole (1978a) and its effect on the radio reflectivity by Poole and Nicholson (14.104.015) and by Baggaley (17.104.034). Poole (1978b, c) investigated the production of ionic lines and molecular bands.

The contribution of meteors to the nightglow was investigated by Baggaley (20.082.020) who concluded that the emission is caused by scattering of solar radiation by interplanetary micrometeoroids rather than by meteoroids in the Earth's atmosphere. Pecina (17.104.038) looked again at the attachment correction. A laboratory investigation of meteoroid ablation was described by Sultanov (18.105.109) in which solid bodies were blasted by Mach 4 supersonic plasmas.

6. Meteor Orbits
(L. Kresák)

Most of the recent advances in the dynamics of meteoroids refer to the two extremes of their observable size spectrum: bright fireballs and fine micrometeoroid dust detected in deep space.

The Innisfree fireball and meteorite recovery (Halliday et al. 1978) provides a third accurate meteorite orbit as noted in section 2 above. Special attention has been paid to the evaluation of the visual observations of the Farmington meteorite of 1890, because its uniquely short radiation age suggested only small deviations from the orbit of its parent body. Levin et al. (18.105.001, 18.105.031) found that the parent body was, in all probability, an Apollo asteroid. According to Simonenko (1977) the general features of meteorite orbits are consistent with their origin in asteroids of $q \leq 1.2$ A.U. Wetherill (18.105.011) pointed out a non-random clustering of the Apollo and Amor objects in the component of their angular momentum perpendicular to the ecliptic; he also showed that this quantity is nearly the same for the Příbram meteorite and 1863 Antinous, and for the Lost City meteorite and asteroid 1943. On the other hand, there is no known asteroidal counterpart to the Innisfree meteorite. The unique Tunguska object of 1908 was identified as a probable extinct fragment of Comet Encke (Kresák 1978b).

Extensive lists of fireball orbits have been published for the Prairie Network and the European Network (see section 2) and some unpublished data is now available from the Canadian and British networks. The available samples of fireball orbits are even internally inconsistent as to the brightness threshold, and in the largest one (Prairie Network) members of major meteor showers have intentionally been omitted. Nevertheless, the resulting distribution of orbits appears to be closer to one of particles exceeding a uniform mass limit, than the results of any other observing program. This is because small objects of high encounter velocity, producing bright but short trails high in the atmosphere, are missing. For the evolutionary problems it is particularly important (and puzzling) that the aphelia

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of these fireballs tend to cluster between 3.5-4.0 A.U. from the Sun, with about one half of all cases between 3.0 and 5.0 A.U. There is definitely no concentration near the orbit of Jupiter, akin to that of short-period comets, and typical cometary orbits of high inclination and very high eccentricity are rare. The orbits are statistically related to the compositional classification based on the atmospheric trajectories, as demonstrated by Ceplecha (20.104.025, 20.104.054).

Orbits of fainter photographic meteors continue to be published (see section 2). The impact of measuring errors on the errors in orbital elements was discussed by Kresák and Kresáková (17.104.007), showing that significant systematic biases are involved, in particular a spurious overabundance of small perihelion distances. Porubčan (20.104.015 and 1978) analyzed the correlations among orbital elements of individual members of meteor showers, and showed that most of these result from the selectivity of encounter geometry. He also suggested and applied a new version of the orbital criterion for establishing stream membership, and examined the relative accuracy of existing photographic catalogues of meteor orbits. The fact that formal solutions sometimes yield hyperbolic orbits was used by Vsekhsvyatskij (20.104.036) to defend the theory of their interstellar origin.

While the orbits of individual meteors are never accurate enough for a dependable reconstruction of their previous orbital history, computations of perturbations by the planets are successfully used for investigating the origin and evolution of meteor streams. Model computations by Sherbaum (18.104.024, 20.104.009 and 1977) elucidate the dispersion and deformations of evolved meteor streams at encounters with the planets. A number of papers on individual meteor streams (Ursids; Emel'yanenko, 19.103.801: Draconids, Perseids, Leonids and Taurids; Katasev and Kulikova, 18.104.015: Pons-Winnecids; Reznikov, 19.104.008: Quadrantids; Bel'kovich et al. 1977: Geminids; Jones, 1978b) deal with such problems as stream ages, ejection velocities, secular perturbations of orbits, and dispersion rates. In some of these papers, the cumulative effect of the Poynting-Robertson drag is also taken into consideration. However, for optically observable meteors its time-scale appears much too long compared with the other effects of aging.

The interest in the nongravitational effects on the motion of meteoroids has been substantially revived by the detection of very small dust particles on artificial satellites and space probes, because in their size range the radiation effects may dominate over planetary perturbations. Soter et al. (20.104.049 and 1978) developed a detailed theory of radiation pressure and Poynting-Robertson drag on spherical particles with general optical properties, including both absorption and scattering. They also used this theory to predict the general behaviour of particles of different composition which might be typical for interplanetary dust. Other theoretical contributions to this problem were made by Lyttleton (18.106.027) and Schwehm and Rohde (1977). Model computations for the combination of the Poynting-Robertson effect, erosion by solar wind, and interaction with interplanetary magnetic and electrical fields were made by Dmitrievskij and Kostylev (17.104.019). Their results point to quasi-periodic perturbations of orbital elements, with progressive changes of periods, and the secular component becoming eventually dominant at certain particle sizes. The constraints set by direct radiation pressure on the maintenance of cometary ejecta within the solar system were discussed by Jambor (18.102.056) and Kresák (17.102.003). The latter paper suggests that these ejecta cannot form compact streams spiralling towards the Sun and detectable as micrometeoroid showers. The acceleration resulting from interplanetary erosion and fragmentation can, under certain conditions, overcompensate the Poynting-Robertson drag. Misconi (18.106.041), treating the rotational breakup of dust particles, suggested that those spiralling in from the asteroid belt cannot reduce their perihelion distances below $q = 1.2$ to 1.3, where intense disintegration by rotational bursting should take place.

In spite of the continuing technical development of detectors for measuring the velocity vectors of micrometeoroid impacts, most of the current observational

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evidence on micrometeoroid orbits is still based on the variation of impact rates with the heliocentric and geocentric distance of the spacecraft, their variation with the sensor orientation, and on the photometry of the zodiacal cloud from deep-space probes. The situation is still rather controversial due to the severe selection effects involved. In general, a considerable enhancement of the measured particle flux is observed when the spacecraft comes closer to the Sun. However, the problem is complicated by the enhancement being also due to increasing impact velocities (Grün et al. 1977). Selection effects on the observed distribution of the orbital elements i, e, a were investigated by Schmidt (1977, 1978) in connection with the data obtained from Helios 1. While the streaming of the β-meteoroids away from the Sun is well established, it remains open whether this is mainly due to collisions or evaporation of larger particles near the Sun. Zook et al. (1978) suggest the existence of two separate populations of micrometeoroids affected by radiation pressure, one escaping on hyperbolic orbits and the other with aphelia significantly increased over those of their parent bodies.

Zodiacal light observations from Helios 1 and 2 indicate the number density of optically active dust particles varying as $r^{-1.3}$ near the Earth's orbit (Leinert et al. 1977) - a significant difference from the distribution of orbits of photographic and radio meteors. From the same observations, the plane of symmetry of the zodiacal cloud is set by $i = 3.0°$, $\Omega = 87°$ (Leinert et al. 1978), which would mean a deviation of 1.7° from the fundamental plane of the solar system. Rather surprisingly, visual observations from Salyut 4 suggest the inner zodiacal light to contain several brighter rays, variable in time. These are attributed by Willman et al. (20.104.044) to the presence of dust streams of cometary origin, which do not decay before the destruction of their individual members. The discrepancies between the orbital inclinations of zodiacal particles, radio meteors, photographic meteors, and comets were discussed by Lebedinets and Manokhina (1978), with the aim of removing observational selection and constructing a common model of the interplanetary dust cloud. Comparative three-dimensional distributions of the potential sources of dust and their near-earth fluxes were deduced by Kresák (1978c,d).

The enhanced and strongly variable micrometeoroid fluxes in the immediate vicinity of the Earth are explained by Fechtig et al. (1978) as caused by electrostatic fragmentation of larger friable bodies in the auroral zone (Dohnanyi and Fechtig 1977) giving rise to micrometeoroid swarms. Another type of discrete event, less frequent but of longer duration, is attributed to the lunar ejecta released by meteorite impacts (Dohnanyi 1977). On the other hand, the concentration of dust in the vicinity of Jupiter, detected by Pioneer 10, appears to be explainable by gravitational focussing (Humes 18.099.153; Bel'kovich 17.104.016; Singer and Stanley 17.106.003). New evidence of a dust cloud near the lunar triangular libration centre L4, based on photographs from the Apollo 15 Command Module, was put forward by Mercer et al. (1978). Although the observing conditions, with the camera shadowed from sunlight and earthshine, were excellent, the faintness of the 16°×12° glare and its distance of 8° from the lunar orbital plane still leaves some doubt which can only be removed by independent confirmation.

7. Meteor Showers
(B.A. Lindblad)

A. PHOTOGRAPHIC, RADAR AND THEORETICAL STUDIES

In the period 1976-78, several theoretical investigations concerning the formation and evolution of meteor streams have been published. The evolution of cometary debris has been studied by Sekanina (Coll. 39 and 1977) and Kresák (17.102.003). Kresák's studies indicate that sub-micron particles ejected from comets cannot form a compact solar-orbiting dust stream which exists over many revolutions. Reported cometary associations of micrometeorite streams observed from space probes are, therefore, difficult to explain.

The possibility of detecting a meteor stream in interplanetary space by the light scattering from micron-sized orbiting dust particles has been studied by Baggaley (19.104.032) and Hughes (20.104.001). Direct observations of localized enhancements in the zodiacal light have been reported by Levasseur and Blamont (17. 106.021 and .061) and attributed to meteor streams. The observations have been analyzed by Hughes (20.106.010) and interpreted in the form of specific stream widths and meteoroid sizes. Sekanina (17.106.087 and Coll. 39) and Sekanina and Miller (17.103.102) have shown that sub-millimeter-sized dust particles recently separated from a comet can, under certain geometrical conditions, be optically observed in the form of a sunward tail. The predicted anomalous tail of Comet d'Arrest has been photographed and photometrically studied by Sekanina (1978). Optical studies of these anomalous tails provide valuable information on the properties of the dust particles.

Further statistical studies of the dispersion in the inclination of meteor orbits have been made by Gaska (14.104.091). A statistical discussion of radio meteor streams observed during the period 1968-69 has been presented by Sekanina (17.104.003).

Simakina (1975) analyzed the circumstances whereby meteor streams observed at Earth might experience encounters with Mercury, Venus and Mars. The secular perturbations by Jupiter and Saturn on the Quadrantid, Delta Aquarid and Alpha Capricornid streams have been studied by Babadzhanov and Zausaev (17.104.037). A review paper on meteor radiants and minor streams has been published by Terent'eva (14.104.021). Andreev et al. (1975) studied the geocentric distribution of meteor radiants and the distribution of geocentric velocities as a function of the elongation from the apex. It is shown that there are no significant differences in the distributions obtained by visual, photographic and radar observations.

A new technique for the determination of meteor radiant activity from single station observations has been described by Jones and Morton (20.031.247) and Jones (20.031.248). It is applicable to both optical and radar data.

Several studies of comet-meteor stream associations have appeared in the literature. The Bootid stream and its association with Comet Pons-Winnecke has been discussed by Reznikov (18.104.049, 19.104.008). Visual observations of the meteor radiant associated with Comet Kohoutek (1973f) have been reported by Terent'eva et al. (19.104.017). Observations of meteors possibly related to Comet Grigg-Skjellerup have also been reported (19.104.072, 20.104.040).

B. VISUAL AND TELESCOPIC OBSERVATIONS

Visual recordings of meteors are reported at about the same level as in previous years. There are few professional groups engaged in visual meteor observations. Our knowledge of the present-day meteor activity, therefore, depends critically on observations carried out by amateur groups. There is a lack of meteor observations in the southern hemisphere.

Regular programs of visual meteor observations were continued in the U.S.A., Canada, Great Britain, the Netherlands, Sweden, Germany, Switzerland, Czechoslovakia, South Africa, U.S.S.R. and New Zealand. A number of these programs are carried out under the guidance of professional astronomers. Several groups are supervised by the American Meteor Society (Sky and Telescope 55, p. 37, 1978).

Short reports of meteor observations in the northern hemisphere have been published by Apeldoorn (14.104.019), Betlem (14.104.087), German (14.104.086, 19.104.026) and Pavlovski (14.104.030). The meteor section of the R.A.S. of New Zealand is preparing a new catalogue of southern hemisphere meteor radiants (Morgan, private communication). Observations in the southern hemisphere have also been reported by Bennett (1975).

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The results of meteor observations made by participants in the International Astronomical Youth Camps have been summarized by Becker (17.104.006 and .043). A number of previously unknown radiants appearing in July and August are reported.

Various amateur groups and meteor societies have published circulars describing their activities. Meteor News is published by a group in Jacksonville, Florida (Sky and Telescope 55, p. 37, 1978). Reports of the Meteor section of the B.A.A. are printed in the J. British Astronomical Association; the Slovak Astronomical Society in Bratislava has issued a new circular: Meteor Reports (in Czech and English). The Nippon Meteor Society publishes a monthly circular (in Japanese) describing their visual observations. Members of the society also record meteors by FM radio techniques (17.104.027).

Tsvetkov (1974) discussed the probability equations for determining the occurrence rates of meteors, including the limiting case of a large number of visual observers. Šulc (1978) describes a method for determining the probability of observing a meteor from the apparent luminosity function. Relations between the size of the geometric and effective field of view for the detection of line sources are derived by Kresáková (20.031.270). Based on data collected at the Onsala and Skalnaté Pleso observatories, Lindblad and Štohl (20.013.026) have studied the errors in the visual magnitude estimates of trained meteor observers. For the Swedish team a probable error of ±0.40 mag was found. A comparison of the magnitude scales of the Onsala and Skalnaté Pleso observing teams showed a systematic shift of about 0.2 mag.

Visual and telescopic meteor observations by amateur groups are regularly carried out under the auspices of the Meteor Section of the Czechoslovak Astronomical Society. These programs have been described by Nováková (1976). Znojil (1978) lists meteor streams detected during the campaigns in August 1966-68 and Storek (1976) summarizes the results of a campaign in 1975. The luminosity function of Perseid meteors was obtained and the visual and telescopic radiant of the Cassiopaeids was studied. Hourly counts of telescopic meteors have been analyzed by Machholz (19.104.001). Kresáková (1978) has investigated the performance of different apertures, magnifications and fields of view of telescopes for meteor recording.

C. INDIVIDUAL SHOWERS

Visual observations of the 1977 Quadrantids have been reported (19.104.031). Radio observations of the Quadrantid shower have been described by Hughes and Taylor (20.104.014) and McIntosh (Coll. 39). Isamutdinov and Fialko (14.104.078) and Bel'kovich et al. (17.104.022) have investigated the structure of the shower. The radiant position and time of maximum activity were studied by Vybornaya (1975). Spectroscopic observations of faint Quadrantid meteors using airborne vidicon equipment are reported by Millman (14.104.010). Simultaneous ground based radar observations of the shower were made in Ottawa.

Visual observations of Perseids are carried out on a regular basis by amateur groups (14.104.027). Spectra of Perseid meteors have been reported by Scitter (17.104.011) and Russell (14.104.041 and .090). The magnitudes of bright Perseids are discussed by Khaimov (17.104.041).

An analysis of photographic orbits of 295 Perseids by Porubčan (20.104.015) showed considerable differences in dispersion among different catalogues. After rejection of 22 orbits the mean period and orbit were determined. The origin and evolution of the Perseid stream has been investigated by Katasev and Kulikova (1975 and 18.104.015).

Visual observations at the Skalnaté Pleso Observatory of the 1946 Draconid shower have recently been evaluated by Kresák and Slančiková (14.104.065). Sporadic meteors observed in the period October 6-10, 1972 have been analyzed for rates, spatial density and luminosity function by Sizonov (18.104.020 and 1976). No Draconid shower was observed.

Sizonov (1975) described visual observations of the 1973 Orionids made by a team of observers. Radar echo studies of Orionid meteors are being continued at the Ondřejov Observatory. A comparison of the radar rates at Ondřejov and Dushanbe by Babadzhanov et al. (20.104.018) indicates considerable structural detail in the stream.

Latipov and Rubtsov (17.104.036) and Kremneva et al. (18.104.016 and 1977) describe Leonid observations in 1966-72. Radar observations of the 1961-69 Leonid returns were analyzed by McIntosh (Coll. 13). The photometry of Leonid meteor trains observed in 1965 has been presented by Buvidajte and Gul'medov (14.104.088).

Results of an extensive visual survey of the Geminid shower in the period 1961-66 have been presented by Rao et al. (1977). The spectra of Geminid meteors have been recorded by Millman and Clifton (17.104.060) using vidicon techniques. Geminid radar observations for the period 1958-74 have been analyzed by Simek (17.104.039). Several concentrations in the stream have been detected. Based on these observations an orbital period of 1.72 years is deduced. Jones (1978b) using a new technique for analyzing periodicities from year to year in meteor shower activity finds an orbital period of 1.49 years. Since the orbital period appears to decrease with particle size the observed differences in period may merely reflect the different limiting magnitudes of the two surveys. Using radar observations Kostylev et al. (1977) have studied variations in the meteor flux and in the mass parameter s during the Geminid activity period.

8. Meteors and the Earth's Atmosphere
(B.A. Lindblad)

Several investigators have studied the interrelation between meteors and various phenomena in the Earth's atmosphere. Optical manifestations of aerosols of assumed meteoric origin have been observed by Link (17.082.077 and 1976). The influence of atmospheric turbulence on the measured flux density of sub-micron particles in the Earth's atmosphere has been studied by Teptin (17.104.032). Hughes (12.106.070) discusses the increased influx to the upper atmosphere that occurs during meteor showers. The influence of twilight effects on the direct counts of meteors has been investigated by Slančiková (14.104.064).

A different kind of atmospheric interaction was considered by Mitra (17.082.012) who suggested that the superrotation of the Earth's atmosphere above 150 km could be explained by the excess orbital angular momentum of impinging meteoroids. McIntosh (20.104.035) has, however, shown that the contribution of meteoroids to this excess is insignificant.

Persistent visual trains associated with bright meteors have been observed for many decades. The faintness of the train luminosity makes the phenomenon difficult to study, and the mechanism responsible for the luminosity is not well understood. The known facts and some mechanisms put forward to explain train occurrence have been reviewed by Hughes (14.104.013). In a series of papers Baggaley (14.104.007, .014 and .059; 17.104.001, 19.104.022, 20.104.031) has studied the physical processes involved.

The role of meteors in ionospheric processes is discussed by Ovezgeldyer and Korsunova (14.104.028 and .057). The formation of sporadic E layers has been investigated by Shuskova (18.104.044) and Latipov and Rubtsov (17.083.052) with regard to meteor activity. Ellyett (18.083.018 and .084) presents a detailed analysis of the problem of meteor-sporadic E correlations. It has been suggested by

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Irkaeva (19.104.016) that the occurrence frequency of magnetospheric ducts is related to E-region instabilities of meteoric origin.

Naidu and Rao (20.083.058) have recorded LF radio signals during the Geminid period and have found ionization irregularities and signal fading which they ascribed to meteor shower activity. In a related study, Rao et al. (17.104.063 and 1976) have recorded meteors by the VHF forward scatter technique. High meteor activity was indicated during the Geminid and Quadrantid peak periods. The diurnal variation of signals agrees with that of visual data collected at the same station.

The duration and amplitude of meteor radar echoes depend critically on the atmospheric conditions. A change in the heat input to the meteor zone affects the atmospheric scale height and thus also echo duration and amplitude. For given mass and velocity, changes in the echo amplitude will produce subsequent changes in the hourly rates of meteor echoes as recorded by a meteor radar of fixed sensitivity.

McIntosh and Hajduk (20.104.017) have investigated the effect of sunrise on the radar echo counts of meteors. The proportion of persistent echoes is shown to increase rapidly after sunrise, an increase by a factor of 2 is reported. There is increasing evidence indicating that the occurrence rate of meteor echoes varies inversely with solar activity. Ellyett (19.104.024) presents a statistical study of this question based on Canadian and New Zealand meteor radar data. A plausible explanation of the phenomenon is that it is caused by a long term variation in the solar heat input to the meteor region. A quantitative treatment of this problem is needed. Lindblad (1978) has found a short term variation in meteor radar rates related to geomagnetic activity and solar wind sector structure. The responsible heating agent in this case is not known with certainty. Joule heating by ionospheric currents associated with the arrival of the corpuscular radiation from the sun has been put forward as a likely physical mechanism.

9. Meteorite Craters and Tektites
(I. Halliday)

Impact cratering on earth and the phenomena associated with hypervelocity impact continue to be actively studied in many parts of the world, both under natural and laboratory conditions. A current compilation of world impact sites (Grieve and Robertson 1978) lists 13 where meteorites have been found, 78 others lacking meteorites but with definitive shock metamorphic effects to confirm their impact origin, and an additional 50 "possible" impact sites. Recent additions to the first group are Sobolev, Siberia (Khryanina and Ivanov 1977) and Morasko, Poland (Freeburg 1966). It seems likely that all large impact structures of the second group with a distinct circular outline have been recognized in North America and Europe. Recently recognized members of this second category such as Ile Rouleau, Quebec and Slate Islands, Ontario resulted from the chance discovery of shocked rocks rollowed by recognition of remnants of the circular form. The crater form of Holyrood (Conception Bay) Newfoundland seems to have been completely obliterated (Engelhardt 1975) and only scattered evidence of shock metamorphism remains. In the Soviet Union, however, where impact structures continue to be confirmed on the average of two or more per year, sites such as Shunak (Fel'dman and Granovsky 1978) Zhamanshin (20.105.154) and Tabun-Khara-Obo (17.105.113) were originally detected by their strong indications of circularity. In Brazil, shock metamorphism in the form of shatter cones has been confirmed at Serra da Canghala, and three other structures in that country, Riachao Ring, Colonia and Sao Miguel do Tapuio have the characteristic form of eroded impact sites.

Impact melt rocks continue to be investigated by detailed geochemical analyses, with Manicouagan among the most thoroughly studied (Floran et al. 1978 and companion papers). Parfenova and Yakovlev (Crat. Symp. p. 843) found that selective vapourization from impact melt compositions leads to a variation from the bulk compositions of the target rocks. Masaitis and Sysoev (13.105.133) have detected a meteorite component in the Popigai melt rocks and similar contaminations at Clearwater East, Brent and possibly the Ries (El Goresy and Chao 1976, Grieve 1978, Morgan et al. 1977, Palme et al. 1978) are interpreted to result from a stony meteorite source. The enrichment in Ni and other siderophile elements at Rochechouart has led to the interpretation by Lambert (Crat. Symp. p. 449) that the impacting body was a Type IIA iron.

The mechanics of explosion cratering and hypervelocity impact cratering have been extensively examined and compared, from theoretical, experimental and observational disciplines with, among other aspects, new light shed on the late stages of cratering, including the formation of central uplifts (see numerous papers in Crat. Symp.). Contributing to an understanding of the substructure of complex craters are comprehensive studies of Decaturville (Crat. Symp. p. 321) and Flynn Creek (Crat. Symp. p. 277) plus the extensive geological and geophysical data from the 1973 borehole at the Ries (Vidal 1977).

Two comprehensive volumes on tektites reach opposing conclusions on their origin. O'Keefe (19.003.135) uses theoretical arguments to reject a terrestrial origin and favours a lunar source. In "Tektites" (10.003.021) however, Barnes and Barnes cite the lack of suitable source material on the moon as evidence for a terrestrial impact origin. Following the latter hypothesis, the origin of the Australasian tektites has been variously proposed as Elgygytgyn by Dietz (19.105.190), a possible crater in Cambodia by Hartung or Zhamanshin (Glass 1978) where the glassy "irghizites" resemble tektites according to Florensky (20.105.057) and Ehmann et al. (20.105.145).

10. Interplanetary Dust
(D.E. Brownlee)

The origin of interplanetary dust and the process by which the zodiacal cloud is replenished remain somewhat enigmatic. It is widely believed that the major dust source is short period comets because these objects are the major producers of the somewhat larger meteoroids which become optical meteors (Millman, 20.106.001). Support for this hypothesis was given by the analysis of Dohnanyi (17.106.079), who concluded that the amount of collisionally produced particles in the asteroid belt is probably very minor in comparison with debris released by comets. Delsemme (17.102.030) and Sekanina (1977), however, have shown that existing short period comets are incapable of producing the approximately 10^7 g s^{-1} required to maintain the zodiacal cloud in equilibrium. They suggested that perhaps this problem can be circumvented if comets such as Encke had been much more active in the past or if short period comets emit appreciable quantities of boulders which later fragment into dust. Parabolic comets release sufficient quantities of dust but most is lost from the solar system due to radiation pressure.

Over the past three years several attempts were made to detect interstellar grains within the solar system. Bertaux and Blamont (18.106.002) suggested that interstellar grains streaming into the solar system may be gravitationally focussed to a "downstream" line behind the sun in a manner similar to the Lyttleton mechanism for the formation of comets. The fact that a particle concentration has not been observed in this region led the authors to conclude either that the local density of interstellar grains is two orders of magnitude below expectation or that the focussing does not occur because of radiation pressure effects or that dust near the solar system is abnormal. Levy and Jokipii (18.131.207) suggested that because interstellar grains are probably charged to a potential of $\sim$3 V, the Lorentz force caused by interaction with the magnetic field in the solar wind, would prevent gravitational focussing and in fact would prohibit some grains from entering the solar system. This effect, of course, is important only for very small grains. McDonnell and Berg (17.012.003) search for anisotropies in five years of Pioneer 8/9

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meteoroid data, which could be attributed to interstellar grains streaming into the solar system. They found no effects and concluded that the density of interstellar particles at 1 AU is <4% of the interplanetary particles for masses $>10^{-13}$ g. Tomandl (17.106.094) discussed techniques for detecting an interstellar component using both spacecraft and lunar microcraters. Greenberg and Schuerman (1978) discussed the possibility of detecting interstellar grains on the upcoming out-of-the-ecliptic (Solar Polar) mission.

Particle dynamics and radiation pressure effects were subjects of a variety of papers. Dohnanyi (Cosmic Dust, p. 527) gave a general review and Lyttleton (18. 106.027) and Kresak (17.102.003) described effects of radiation pressure and collisions. Dohnanyi's results indicate that catastrophic collisions are the major factor limiting particle lifetimes for particles >1 μm. Lifetimes of 10^3 to 10^5 years are typical for particles in the 1 μm to 10 cm size range. Kresák concluded that progressive fragmentation prevents classical Poynting-Robertson inward spiraling of small particles in meteor streams. He also concluded that particles <100 μm cannot remain inside tightly clustered meteor streams for more than a few orbits before they are dispersed. Destruction of grains by rotational bursting was discussed by Misconi (18.106.041) and Paddack and Rhee (17.106.107). Reznova (17. 106.024) computed temperatures of dust grains in the interplanetary medium and Lamy and Jousselme (20.106.089) discussed the temperatures and lifetimes of ice grains at various distances from the Sun. Soter et al. (20.106.049) and Schwehm et al. (17.106.092) showed that the radiation pressure force never exceeds gravity for compact dielectric particles in the solar system. The theory of β meteoroids has been expanded and now includes subclasses of objects influenced to various degrees by radiation pressure (Zook et al. 1978).

Two special effects were discovered which are caused by the interaction of planets and the meteoroid complex. Alvarez et al. (17.106.018) reported a two order of magnitude increase in the flux of nanogram particles impacting Pioneer 10 and 11 as they approached Jupiter. Singer and Stanley (17.106.003) showed that the observed concentration effect can be explained solely by gravitational focussing. Near the earth, the highly eccentrically orbiting spacecraft, HEOS, detected clusters of particles mainly within 10 earth radii. Fechtig et al. (1978) explained that many of the particle clusters are fragments of 10 to 10^6 g meteoroids disrupted in the Earth's auroral zone by electrostatic charging. Some of the clusters were described as ejecta from lunar craters.

Dust measurements by the Helios spacecraft extended our knowledge of meteoroid flux to within 0.3 AU from the sun. The dust detector measured a radial dependence of dust density of $R^{-1.3}$ for submicron particles (Grün et al. 1977). This result is consistent with zodiacal light measurements made on the same mission (Leinert et al. 1977) and is compatible with radial dependence of particle density between the Earth and Jupiter measured previously by Pioneer 10 and 11.

Considerable progress has been made towards understanding the variety of phenomena recorded in lunar microcrater records but several problems remain. Estimates of meteoroid density determined by measurement of microcrater depth to diameter ratios yield conflicting results which have not been resolved. Measurements by Mandeville (20.094.473) indicate that most particles in the 1 μm - 100 μm size range have densities of 3-4 g cm^{-3} while results of Nagel et al. (20.094.472) indicate three groups of particles with densities corresponding to iron, silicate, and fluffy materials. Measurement of the chronological deposition of individual microcrater formation events has shown a strong variation with time. This result is interpreted as either due to a change of the meteoroid flux, a change in the solar flare flux which is used as a dating clock, or due to a lunar surface process which may selectively shield impact pits (Zook et al. 1977). The best measurement of the size distribution over the entire microparticle range was derived by crater counts on lunar rock 12054 (Hartung et al. 1978, 9th Lunar and Planetary Sci. Conf.).

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In the cumulative crater frequency plot the only major feature in the size range 0.1 to 1000 μm is a broad dip occurring roughly from 1 to 30 μm. This feature has been seen on several lunar samples and is believed to be an indication that the size distribution of interplanetary dust is bimodal. It is significant that unshielded portions of 12054 contained very high densities (10^6-10^7 cm^{-2}) of submicron craters. It is now generally believed that lunar surfaces whose crater frequency curves flatten out before reaching the submicron region and do not have high crater densities do not truly represent the meteoroid size distribution but are erroneous due to partial shielding by thin dust layers or accreta (Morrison and Zinner 19.106.022).

Micrometeorite and microcrater experiments continued to collect interplanetary dust for laboratory studies. Hemenway et al. (17.106.017) collected microcraters on a Skylab experiment and found residue lining several craters. Atmospheric collections of particles were conducted by Yabuki et al. (18.106.067) using aircraft and Wlochowicz et al. (17.051.025) using balloons. Brownlee (Cosmic Dust p. 295) and coworkers continued collection and analysis (Flynn et al. 1978, 9th Lunar and Planetary Sci. Conf.) of micrometeorites using NASA U-2 aircraft. These particles have provided a highly detailed characterization of interplanetary dust. Although several classes of particles have been identified the most common are black aggregates of submicron grains and have elemental compositions similar to primitive carbonaceous meteorites. These particles, although similar to known meteorites, have differences which indicate in many cases they are a new type of extraterrestrial material not seen in meteorites. Although typical particles are compact and have densities in the range of 2-4 g cm^{-3}, several very porous particles were observed which had densities on the order of unity or possibly somewhat less.

Although "cosmic spherules" from deep sea sediments have been studied for nearly a century, recent investigations with modern analytical techniques have produced important new findings. Shimamura et al. (1977) made isotopic measurements on individual magnetic spheres and found $^{40}K/^{41}K$ ratios as much as 40% to 70% above terrestrial. The enhancements were interpreted as due to spallation reactions induced by high energy cosmic rays and are evidence supporting an extraterrestrial origin for the particles. The authors suggested that the spherules are molten droplets produced by atmospheric ablation of meteoroids. Parkin et al. (19.106.015) did optical, SEM, and X-ray diffraction analyses on iron and stoney spheres. They found stoney spheres to contain olivine and magnetite often with the olivine crystals being organized, aligned across large fractions of the spherule. Parkin et al. suggested a novel interpretation of the spheres not as ablation droplets of meteoroids but as objects formed in space and not greatly altered by atmospheric entry. They suggested that the spherical particles may have been produced in space by collisions or by violent eruptions and electrical discharges which may have occurred during the accumulation stages of comet formation. Brownlee et al. (1978) analyzed a large number of deep sea spheres in the 100 μm to 1 mm size range and found that more than half of them contain roughly solar elemental abundances for major and minor elements, except for sulfur which is often highly depleted. These stoney spheres are composed of olivine and magnetite crystals surrounded by iron rich glass. The internal textures of the spheres indicate rapid crystallization from a melt and are identical to common textures found in fusion crusts of chondritic meteorites. Ganapathy et al. (1978) reported trace element analyses which proved that some of the spheres are undifferentiated solar system material. These two groups concluded that most of the cosmic deep sea spheres are solidified droplets of meteor ablation debris.

In a unique analysis Ney and Merrill (18.103.144) were able to measure the angular scattering function of dust emitted by comet West. The scattering function, derived from combined optical and thermal infrared observations, is consistent with partially dirty dielectric grains with radii of approximately 1 μm.

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